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APPENDIX 1

Timing differences of Mars88 DCF77 time synchronisation

Internal Report at ETHZ by Fortunat Kind

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Timing differences of Mars88 DCF77 time Synchronisation

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1 Introduction

During initial experiments for the application of array techniques to ambient vibrations (PhD thesis F. Kind), the question of the precision in time synchronisation arouse. More precisely the precision of Lennartz Mars88 instuments synchronised with the DCF77 signal is concerned.

During the PhD thesis of Robert Arlitt at the ETH Zurich (Tomography) he did some comparisons between DCF77 antennas and GPS receivers. The DCF antenna have internal delay in receiving the signal. Robert Arlitt and Christoph Bärlocher tried to determine this delay and measured the delay of the antenna output signal (one puls each second) against the second indicated from a GPS. The delays were not constant, but varied in a range corresponding to the 10ms imprecision indicated by the manufacturer. The measured time delays are shown in table 1.

Mainly two questions had to be answered to make array measurements with Mars88 recorders and DCF77 synchronisation possible: First, is the antenna delay sufficiently constant and balanced by the internal timing system to correct timing precision down to 1ms? And secondly what are the needed corrections? The relevant time scale for the planned measurements was in the order of 10 minutes, so the interest in stability was also mainly for this time scale.

A first set of comparisons to answer these questions was done in winter 1999/2000. As the time correction was then planned in the time domain and just by shifting the recorded data by an integer number of samples. A second set of test was done in winter 2002 because the instruments used for the SESAME project were not all the same as in the previous experiment. The timing correction was changed into the frequency domain, allowing in a simple way to correct to a higher precision than the 2ms of the smallest sampling period.

2 First series of comparisons (February 2000)

The tests of the relative timing precision of the Mars88 instrument was in three stages. First stage was a comparison of two instruments over ca 15 minutes, so as to verify the short term stability of the time shifts. In a second stage the long term stability of the shift and the precision of the freely running timing system was tested over several days. Thirdly the time shifts of the individual instruments relative to the reference instrument E007 was done. For all tests the experimental setup was the same, recording of some signals synchronously on the reference instrument and the instrument to be tested.

One sensor was deployed and connected to a splitter box, from which the signal was transmitted to both the reference instrument and the test instrument. In this way the signal was 100% identical on both recorders. 2ms sampling was chosen, to hae the highest possible resolution in the time domain for comparing the signals. In a first evaluation the time shifts were determined in the time domain. The results shown here are from a reevaluation of the time shifts in the frequency domain (phase differences), the resulting values are identical from both methods.

short term stability

The instruments compared first were numbers E027 and E028. The location of the test was East of the city of Basel in the Hardwald recreational forest. The test was done beginning of february, so the ground in the forest was frozen. The E-Lab people suggested that the Mars88 timing system needed approximately 15 minutes to set itself up properly, so as to stabilize the regulation of the quartz. Therefore the instruments were switched on and after the time was decoded from DCF, at least 15minutes have been waited before switching on the recording. The location of the test was in the basement of the HPT, figure 1 shows pictures of the setup.

set number	serial number	delay	relative to 007
DCF_Receiver001	B-0403	44ms (40-48)	-2
DCF_Receiver002	B-0363	43ms (40-46)	-3
DCF_Receiver003	B-0400	43ms (38-46)	-3
DCF_Receiver004	B-0406	45ms (38-48)	-1
DCF_Receiver005	B-0362	39ms (36-42)	-7
DCF_Receiver006	B-0378	45ms (42-48)	-1
DCF_Receiver007	B-0365	46ms (40-52)	0
DCF_Receiver008	B-0393	44ms (40-50)	-2
DCF_Receiver009	B-0408	35ms (32-42)	-11
DCF_Receiver010	B-0373	42ms (34-46)	-4
DCF_Receiver011	B-0375	34ms (30-36)	-12
DCF_Receiver012	B-0383	34ms (30-36)	-12
DCF_Receiver013	B-0369	36ms (32-40)	-10
DCF_Receiver014	B-0392	44ms (38-48)	-2
DCF_Receiver015	B-0395	34ms (30-42)	-12
DCF_Receiver016	B-0386	43ms (40-46)	-3
DCF_Receiver017	C-0427	45ms (42-48)	-1
DCF_Receiver018	C-0424	24ms (16-28)	-22
DCF_Receiver019	C-0425	36ms (28-42)	-10
DCF_Receiver020	C-0429	36ms (32-44)	-10
DCF_Receiver021	C-0430	36ms (30-42)	-10
DCF_Receiver022	B-0382	35ms (30-36)	-11
DCF_Receiver023	B-0409	40ms (34-48)	-6
DCF_Receiver024	C-0432	38ms (34-50)	-8
DCF_Receiver025	B-0389	44ms (34-48)	-2
DCF_Receiver026	unknown		NaN
DCF_Receiver027	B-0364	48ms (?)	2
DCF_Receiver028	C-452	46ms (?)	0
DCF_Receiver029	C-459		NaN
DCF_Receiver901	B-0402	39ms (36-42)	-7
DCF_Receiver902	C-0426	41ms (38-44)	-5
DCF_Receiver903	C-0431	43ms (38-48)	-3

Table 1: Table of DCF antenna delays from a comparison of the DCF pulses measured on the antenna and the corresponding time from a GPS instrument.

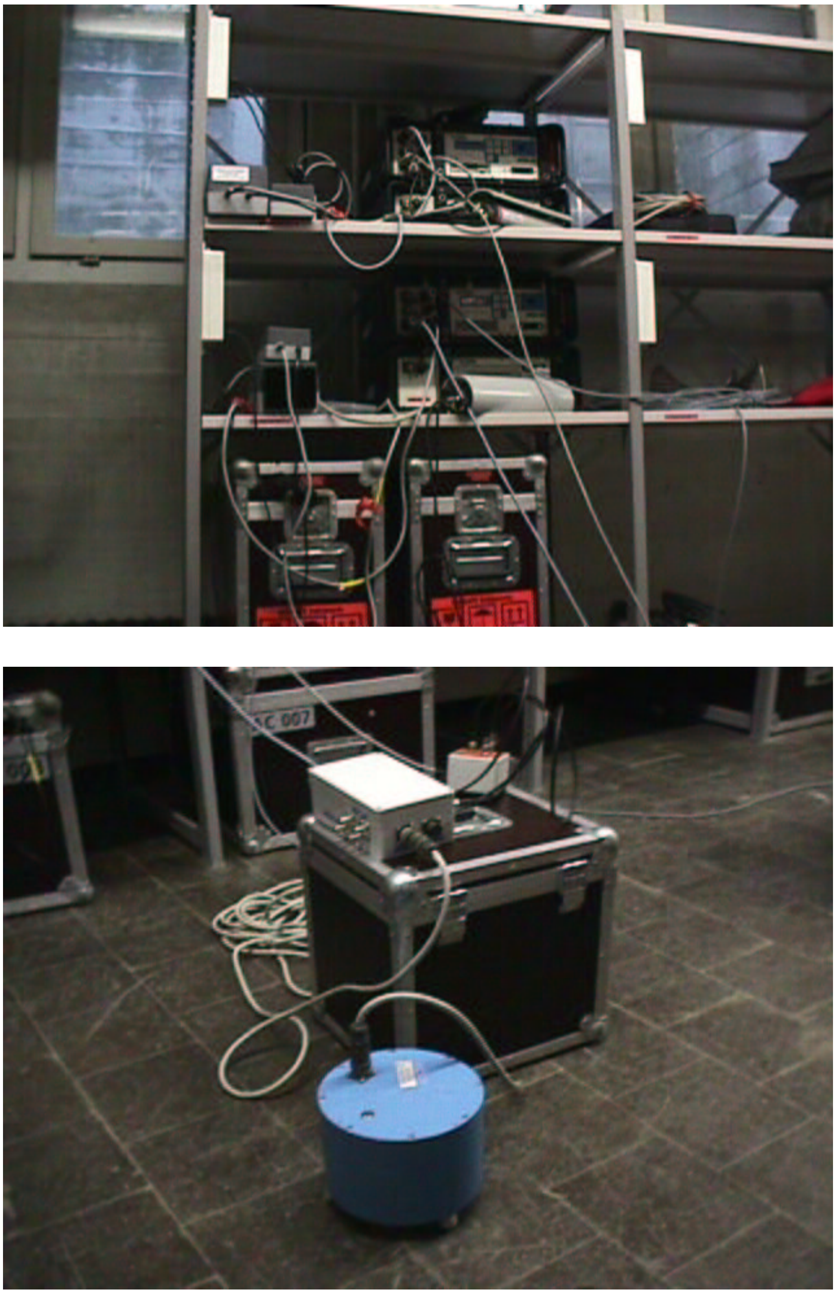

Figure 1: Setup of the instruments for the short term stability test in winter 2000. The later determination of the individual time shifts was done in the same manner.

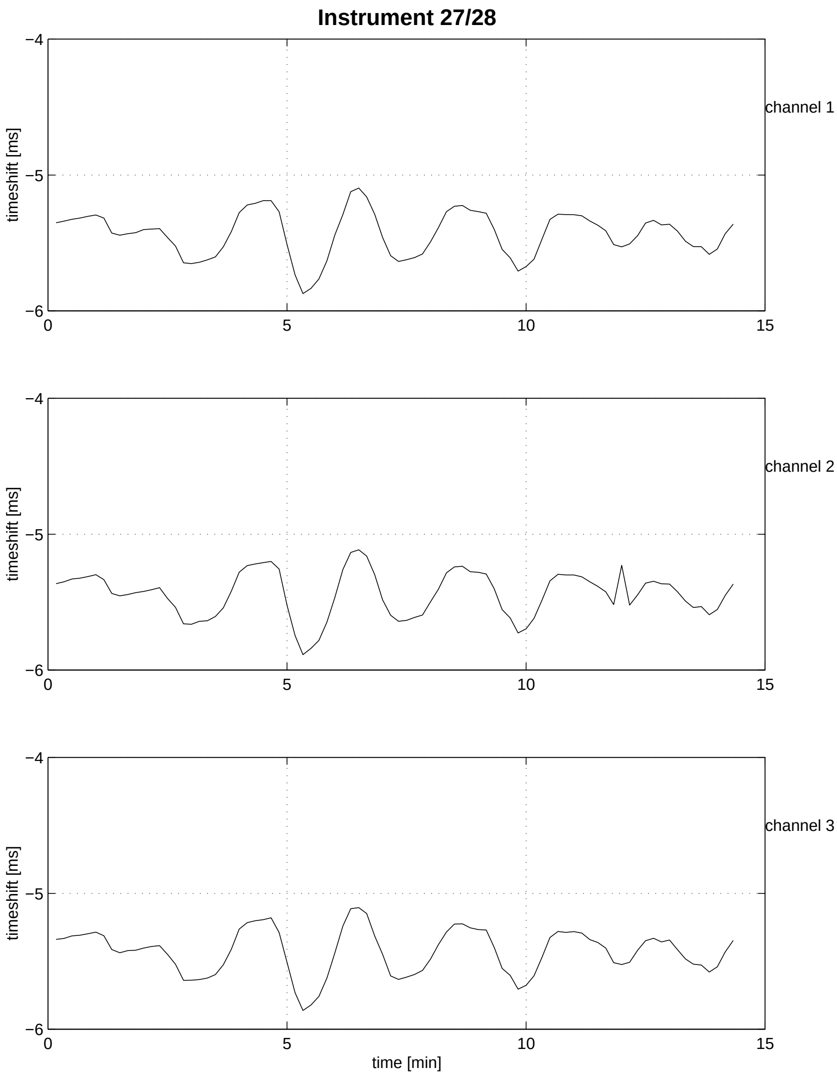

Figure 2: Instrument27-28

Figure 3:

Figure 2 shows the result from the reevaluation. The time shifts on all three channels for 10s windows are shown, varying between -6 and -5 milliseconds. The standard deviation for the variation was below one millisecond, no drift was visible in the 15 minutes. This was incurraging and suggested a long term test.

long term stability

For the long term tests two instruments were set up on the roof of the institute, instruments E007 as future reference and instrument E008 for the test. Again the two instruments were connected to the same sensor, figure 3 shows the setup. The instruments were set to record every quater of an hour for one minute. After three days the DCF antenna of the instrument E008 was disconnected. 24 hours later the antenna was connected again and the recording continued for another few hours (every quater of an hour).

The resulting time shifts evaluated from phase differences in the spectrum of 10s windows are shown in fiugre 4. The differences fluctuate arround 1ms

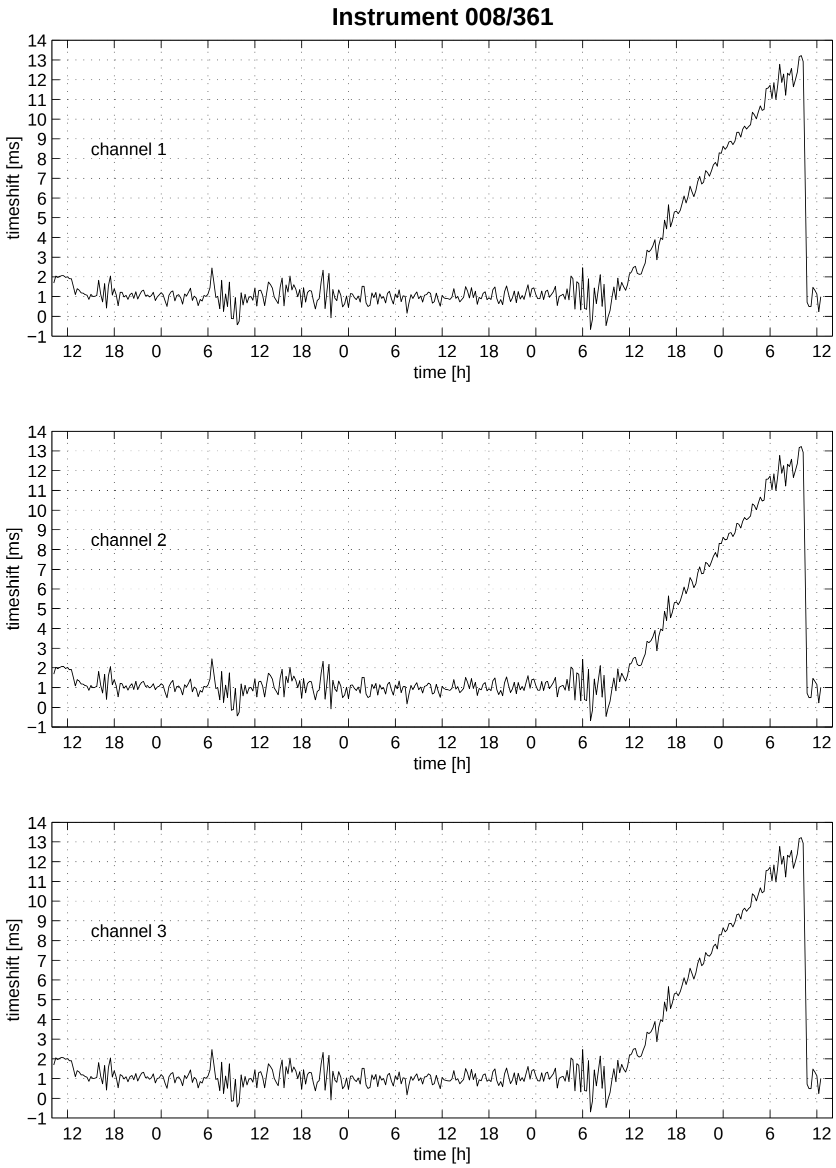

Figure 4: test2000long

Instrument	m88-id	ch0±std	ch1±std	ch2±std	mean±std
008	361	1±0	1±0	1±0	1±1
009	360	0±0	0±0	0±0	0±0
010	358	1±0	1±0	1±0	1±0
011	344	1±0	1±0	1±0	1±0
012	349	1±0	1±0	1±0	1±0
013	351	3±0	3±0	3±0	3±0
014	345	0±0	0±0	0±0	0±0
015	353	1±0	1±0	1±0	1±0
016	356	2±0	2±0	2±0	2±1
028	350	-2±0	-2±0	-2±0	-2±0
029	359	-2±0	-2±0	-2±0	-2±0
027	327	1±0	1±0	1±0	1±0

Table 2: Table of time shifts from 2000 in terms of 2ms samples

with deviations in the order of 1ms. In the first 2 hours of the test the shifts remained constant. After disconnecting the DCF antenna the timing drifted at a constant rate to 12ms during 24 hours, coming back to a synchronised level within 15 minutes after reconnecting the antenna.

time shifts 2000

The two test indicated that the time shifts were stable on a time scale of 10minutes and even for several days, with fluctuations in the order of 1ms or smaller. Table 2 gives the time shifts calculated as averages from approximately 5 minues of data per sensor. The shifts are given in number of 2ms samples. In table 3 the actual values are given, rounded to one decimal place.

3 Second Series of comparisons (March 2002)

The second test was necessary because the instruments used for the SESAME array measurements were not identical to the initial set of instruments. This time the sampling rate was set to 8ms and 25 minutes of data were recorded. The instruments had been synchronizing for 24 hours beforehand, except for number E016, which had been switched on just about 15 minutes before the test. Each instrument was connected to its own sensor, with the reference

Instrument	m88-id	ch0±std $[ms]$	ch1±std $[ms]$	ch2±std $[ms]$	mean±std $[ms]$
008	361	2.1±0.5	2.1±0.5	2.1±0.5	2.1±0.5
009	360	-0.9±0.2	-0.9±0.2	-0.8±0.2	-0.8±0.2
010	358	1.6±0.1	1.7±0.1	1.7±0.1	1.6±0.1
011	344	1.4±0.1	1.4±0.1	1.4±0.1	1.4±0.1
012	349	2.5±0.4	2.5±0.4	2.5±0.4	2.5±0.4
013	351	5.5±0.1	5.5±0.1	5.5±0.1	5.5±0.1
014	345	-0.2±0.1	-0.2±0.1	-0.2±0.1	-0.2±0.1
015	353	1.7±0.2	1.7±0.2	1.7±0.2	1.7±0.2
016	356	3.2±0.5	3.2±0.5	3.2±0.5	3.2±0.5
028	350	-4±0.4	-4±0.4	-4±0.4	-4±0.4
029	359	-4±0.1	-4±0.1	-3.9±0.1	-4±0.1
027	327	1.4±0.4	1.4±0.4	1.4±0.4	1.4±0.4

Table 3: Table of time shifts from 2000

Instrument	m88-id	Sensor	cable
E007 (ref)	354	Q336	007
E002	357	J194	002
E003	347	Q332	003
E004	346	Q338	004
E008	361	Q337	008
E009	360	Q335	009
E010	358	Q334	010
E013	351	Q333	013
E014	345	501	501
E016	356	502	502
E019	324	503	503
E021	323	Q339	006
E022	352	Q341	909 (reserve)

Table 4: Combinations of the instruments and sensors for the test in 2002

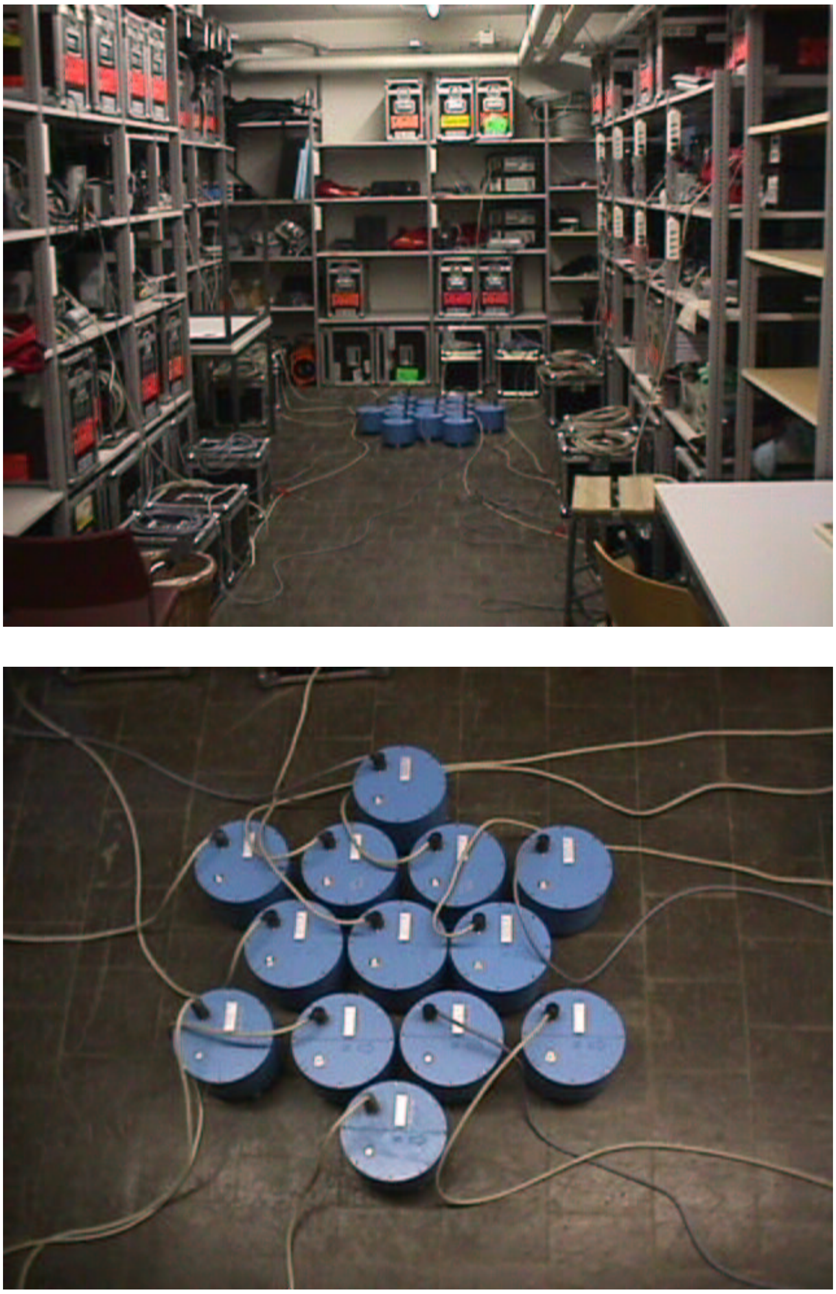

Figure 5: Setup of the instruments for the time shift determination in winter 2002. All instruments recorded 25minutes synchronously, the reference was in the center.

Instrument	m88-id	ch0±std $[ms]$	ch1±std $[ms]$	ch2±std $[ms]$	mean±std $[ms]$
E002	357	-0.8±0.2	-0.4±0.1	-0.4±0.2	-0.6±0.2
E003	347	0.5±0.3	0.4±0.3	-0.5±0.3	0.1±0.5
E004	346	2.1±0.6	1.9±0.6	2±0.5	2±0.6
E008	361	0.9±0.2	1.4±0.3	1.3±0.2	1.2±0.3
E009	360	-0.5±0.7	-0.8±0.5	-0.7±0.5	-0.7±0.6
E010	358	0.6±0.5	0.5±0.3	0.7±0.4	0.6±0.4
E013	351	5.6±0.7	5.9±0.7	6.1±0.7	5.9±0.7
E014	345	0.8±0.5	1.2±0.5	1.1±0.5	1±0.5
E016	356	3.3±0.9	4.1±0.9	3.8±0.9	3.7±1
E019	324	1.6±0.6	1.9±0.6	2±0.6	1.8±0.6
E021	323	-2.5±0.6	-2.3±0.5	-2.1±0.5	-2.3±0.5
E022	352	-0.2±0.4	-0.4±0.3	-0.2±0.3	-0.3±0.4

Table 5: Table of time shifts from 2002

sensor in the center (figure 5). Again the location of the test was in the basement storage location of the instruments for convenience. To insure DCF reception a repeater is installed there, amplifying the DCF signal.

The resulting time shifts are listed in table 5, figures 7-18 show the variability of the time shift during the test. The variability of the time shifts during the recording period is various. Inmstrument E008 (figure 7) has a nicely constant time shift with variations mainly on channel 1 in the order of 0.5ms. On the other hand have other instruments oscillations of the time shift in the order of 1ms and more (figure 13) or the instrument has even a drift of 2ms over 25 minutes (15). A possible deteriorating influence might be the basement location within strong reinforced concrete steel walls. On some Instruments the signal reception LED does not flash in the regular 1s intervalls, but has some higher irregular frequency, causing the instruments to take a longer time to synchronize. To have better answers a test repetition outdoors and possibly with an additional

4 Comparison Set 007 and Marslight with GPS

In the array measurement in the Basle area in april 2002 the Potsdam group (Matthias Ohrenberger, Frank Scherbaum) and our Swiss group (F. Kind) worked together with a mixture of Lennartz Mars88 with DCF synchronisation and MarsLight with GPS synchronisation. To have a handle on the time shifts between the instruments, the ETH instrument 007 and the Potsdam Mars light 12G were set up side by side with maybe 40 cm distance between the centers of the sensors. The data from april 10 (second day) are used, as a recording error with the MO of the ETH instrument gave no useful overlap for the first day.

The GSE data from Potsdam was converted with the software "codeco3" into SAC ascii, which was converted into the Mars88 ASCII format with a matlab routine. Time shifts were calculated in 10s windows in the frequency domain. The amplitudes between the different instruments varied by a factor of about 15, so the time series were normalized with their respective absolute maximum values before comparison. A time span of 2h 50min was available for comparison, the full time series was used, resulting in 1020 time windows for comparison. The expected time shift was around 40ms, so a "preshift" of this order was applied to avoid problems of aliasing for the time shift determination.

The resulting time shift was actually exactly 40ms, as the top part of figure 6 illustrates. The result was identical on all three components (figures 19, 20). Below the histogram 10 segments of 20 samples are shown, the segments are evenly distributed over the time range. The dotted curve in the background is the Mars light reference signal, GPS synchonised. The magenta dash dotted curve is the MArs88 DCF synchonised signal. The green continuous line gives the time shifted, corrected Mars88 time series.

The time shift on the vertical component seems to be stable and precise to one sample. Channel 1 is also ok, but on Channel 2 there seem to be larger differences, especially with the amplitude of the signals. As the time shift is identical as on the other channels and the visualization of the results seem still plausible, the channel 2 component was not further investigated. Possibly a strong disturbance at some point in the signal caused the normalization to cause unnaturally low amplitudes in the signal, which could be the reason for the different amplitudes.

5 GPS Synchronisation Mars88

The Mars88 of the SED had initially only DCF synchronisation built in; the GPS receivers available for the instruments are a later addition. The GPS

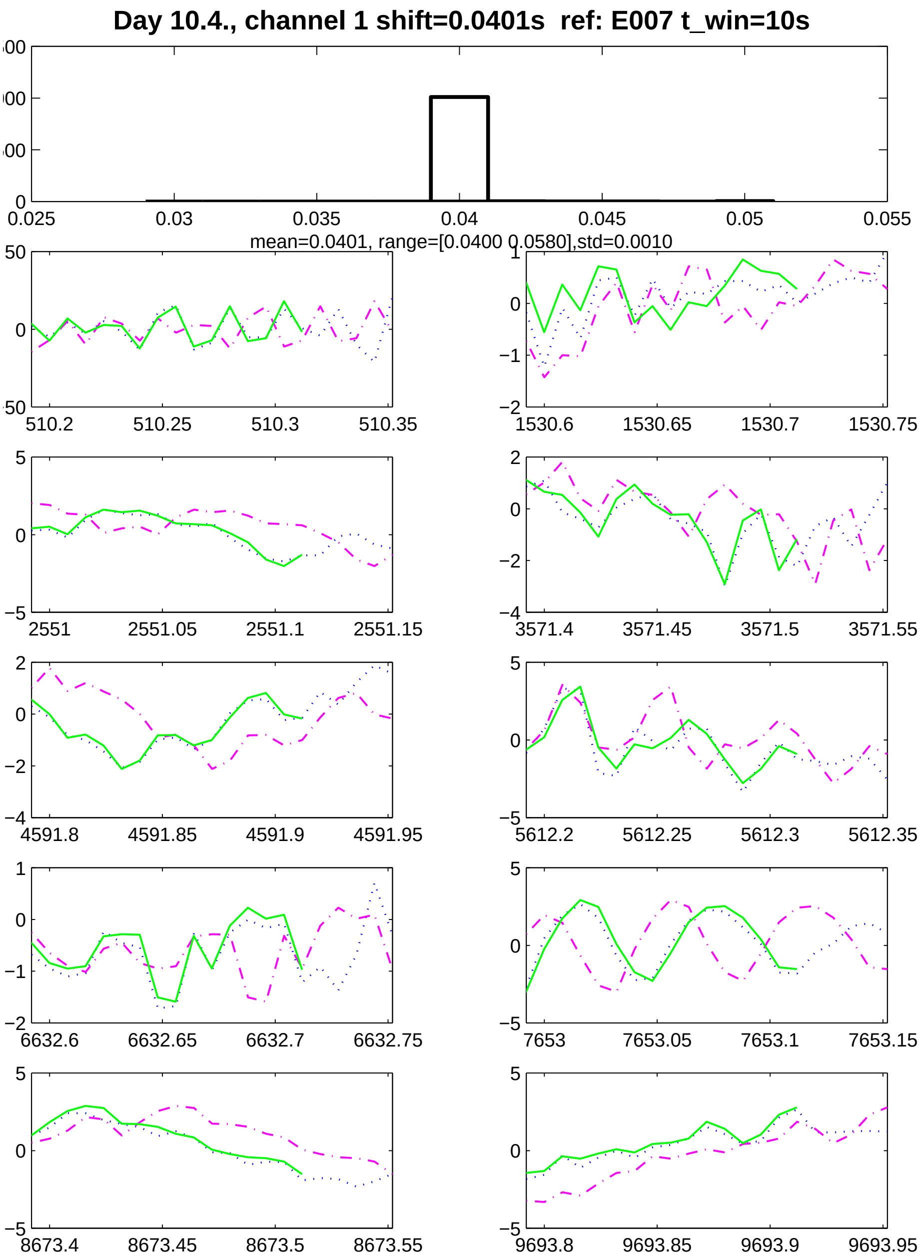

Figure 6: Time shift between Mars light PS 12G from Potsdam and Mars88 DCF E07 from ETH during the measurement of April 10 2002. Channel 0 (vertical) is compared in the frequency domain on 10s windows.

receivers decode the GPS signal to synchronize an internal clock. From this clock a DCF like signal is derived and fed through an antenna cable to the DCF reception socket on the Mars88. The advantage of the GPS is mainly the higher precision and continuity how the input DCF signal is received. For the GPS receiver of the SED the snchronisations are timed to every 30 minutes or every hour for a few minutes, in the rest of the time the clocks are on free run (12ms error in 24hours). This setup is due to the high power consumption of the GPS receivers.

6 Conclusions

Clearly the time shifts between the individual Antennas of the instruments are better than the 10ms indicated by the manufacturer. But even over short time periods the time shift varies in the order of 1ms. While behaviour like in figure 7 is incurragingly constant, the graphs in figure 15 and 13 are worrying, as both show a certain drift over a time period of 25 minutes and the second one has even some varyiations of up to 2ms. The results for the tests at different times agree with differences in the order of 1ms, but not better. The difference between the delays relative to the GPS (relative again to the delay of the reference instrument) has no correlation to the measured time shifts. This indicates that the fluctuations of the incoming signal are damped strongly by the internal timing system, but not sufficiently to remove all fluctuations.

Possible reasons for the variations are on one hand in the hardware, that is specified for 10ms imprecision and not less. The electronic components are operating at the lowest limit of the specified voltage, giving an uncertainty on the switch time for identifying a pulse. Or the coils in antenna and instrument have loosened slightly from their core, causing some uncontroled delay times.

Furthermore the sensitivity of the receiver electronic is slightly different from instrument to instrument and might cause the more sensitive instruments to react to the direct signal from the outside, while others react to the slightly delayed signal from the repeater. A mixture could cause the flashing of the external time LEDs by identifying multiple pulses.

With the data currently available, we are not certain whether the time shifts are fluctuating in the order of up to 2ms or are constant in the order of the tabulated values. For array experiments corrections with the tabulated values are better than no correction, but the achieved precision will be in the order of 2ms and not 1ms as was expected from the initial tests. To further improove the knowledge the information on the timing precision, an outdoor experiment with all instruments and a reference timing from a GPS would be needed.

A Shift results 2002 for all ETH recorders

We collect here all the figures from the time shift determination in 2002. All instruments concerns all the available instruments for the specific measurement for the SESAME project in Basle.

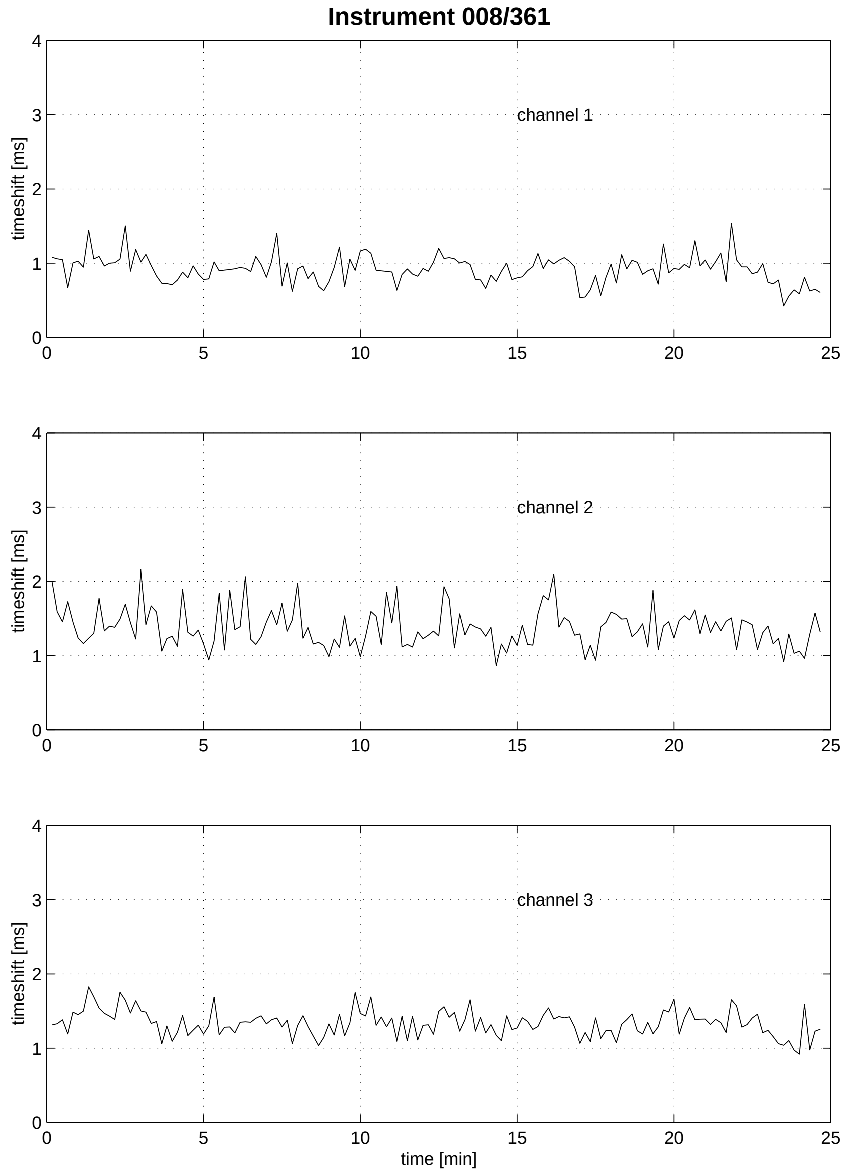

Figure 7: Instrument008-361

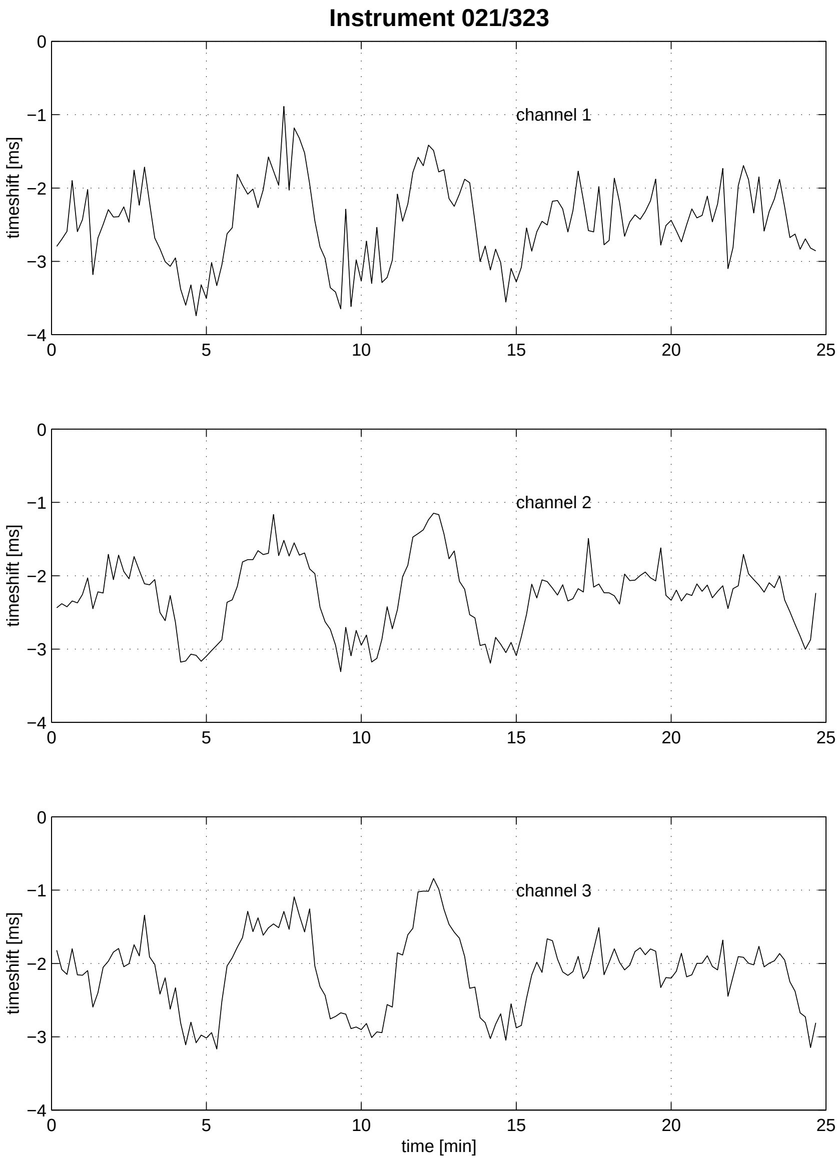

Figure 8: Instrument021-323

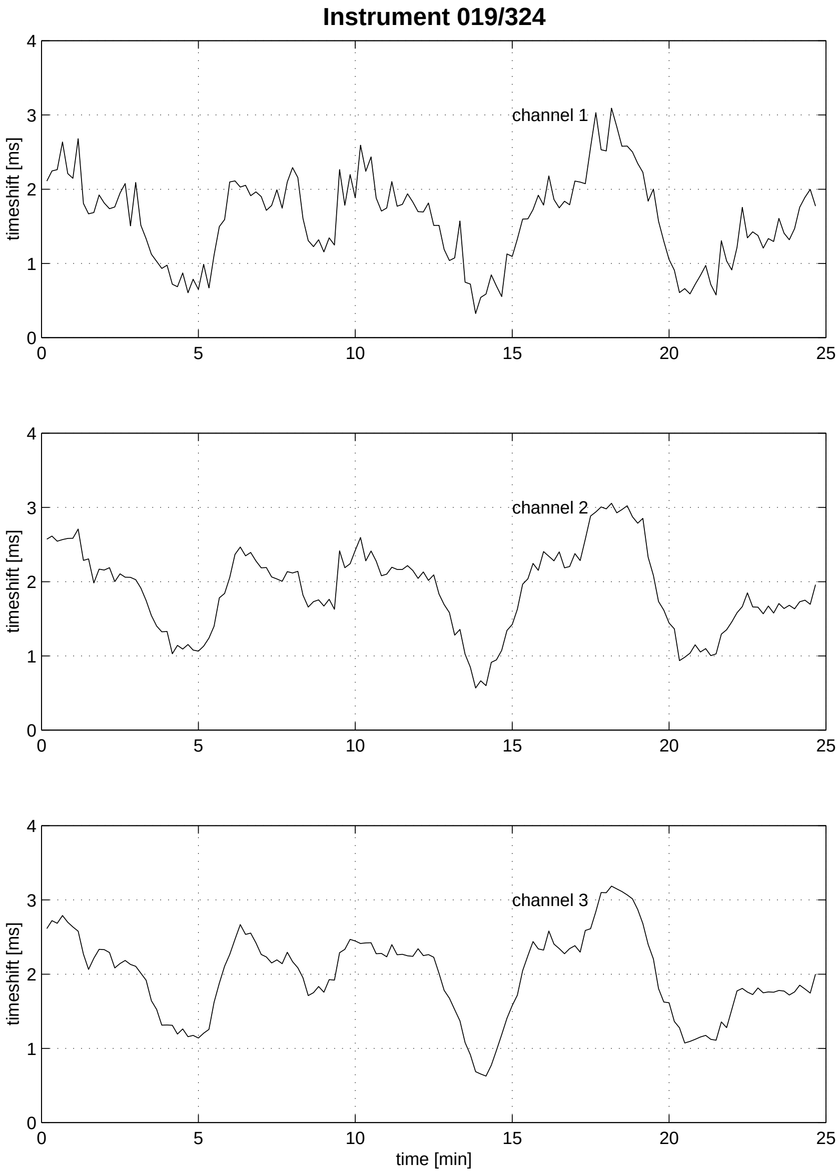

Figure 9: Instrument019-324

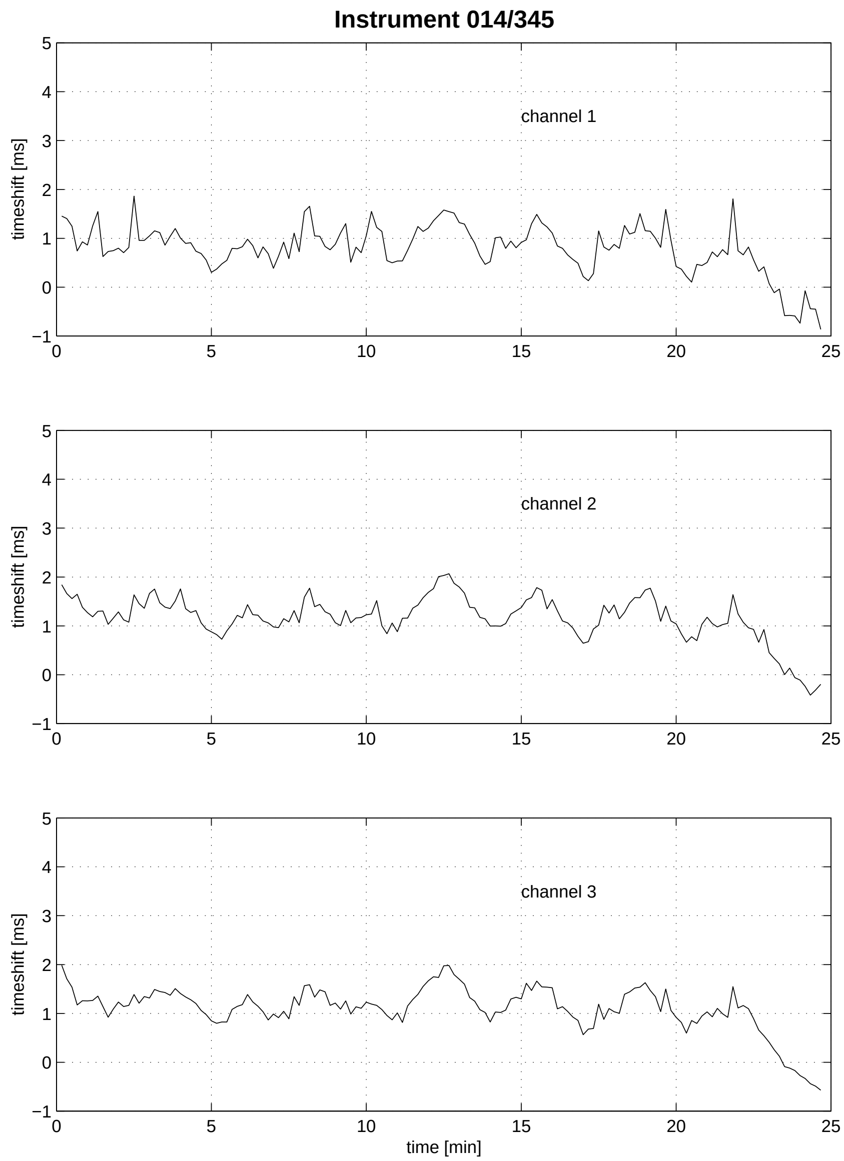

Figure 10: Instrument014-345

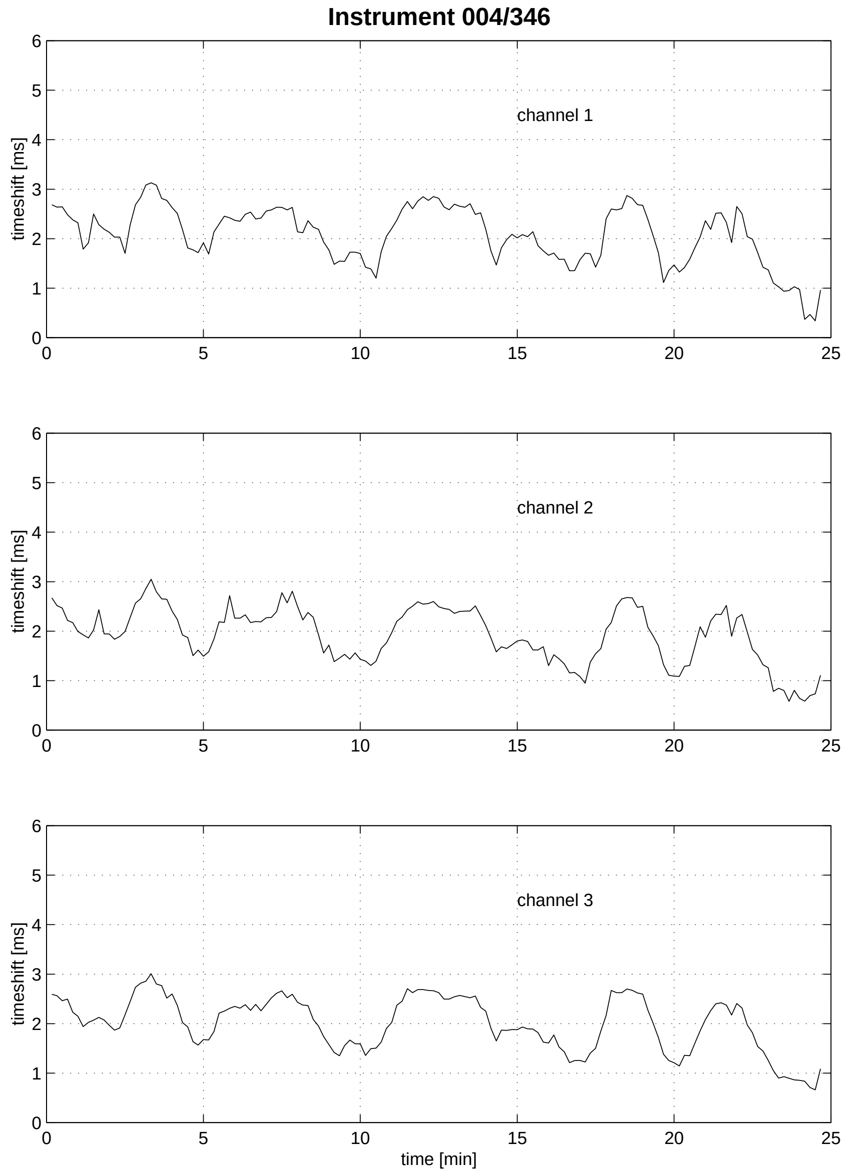

Figure 11: Instrument004-346

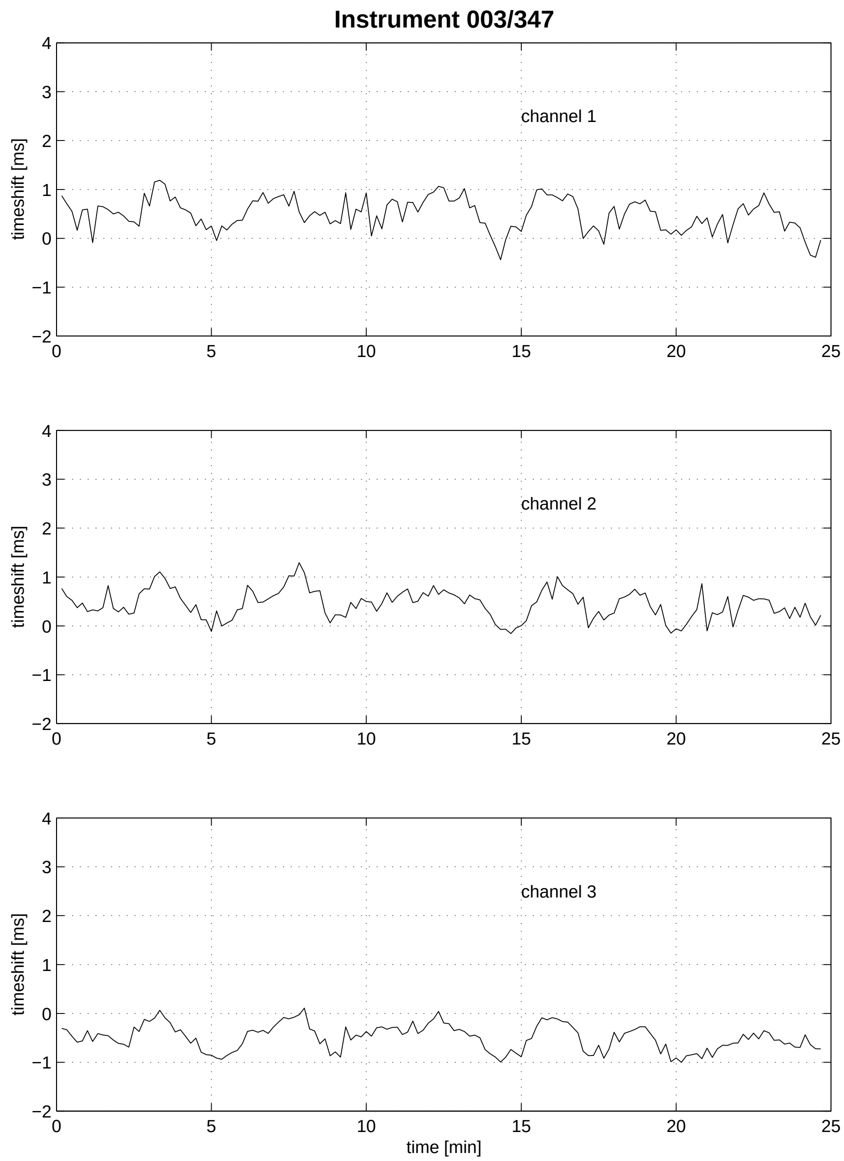

Figure 12: Instrument003-347

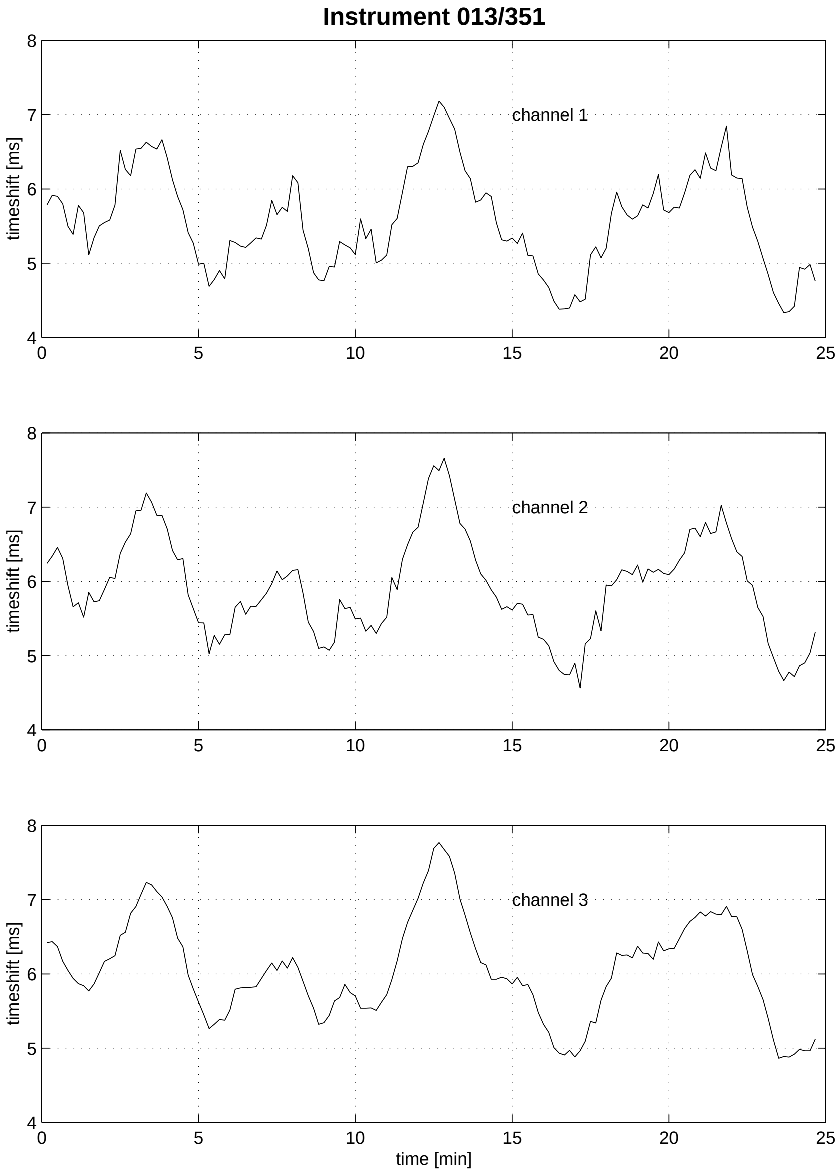

Figure 13: Instrument013-351

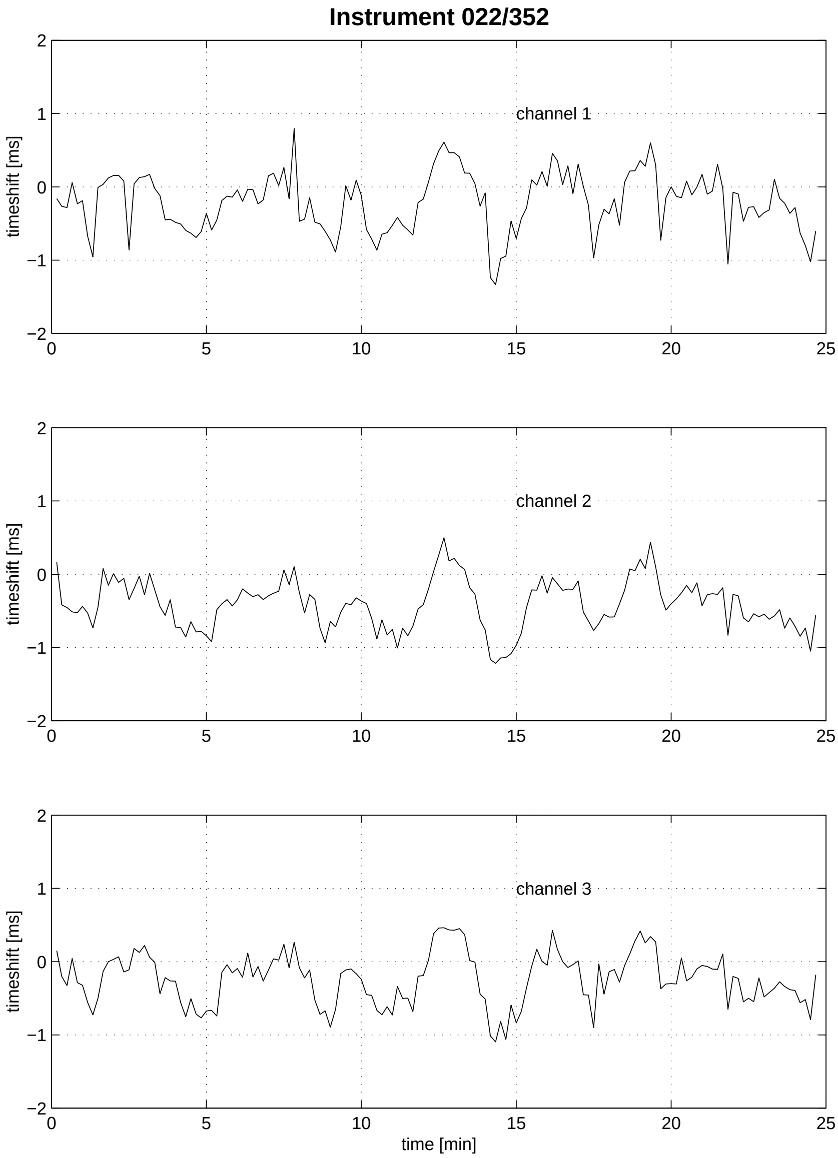

Figure 14: Instrument022-352

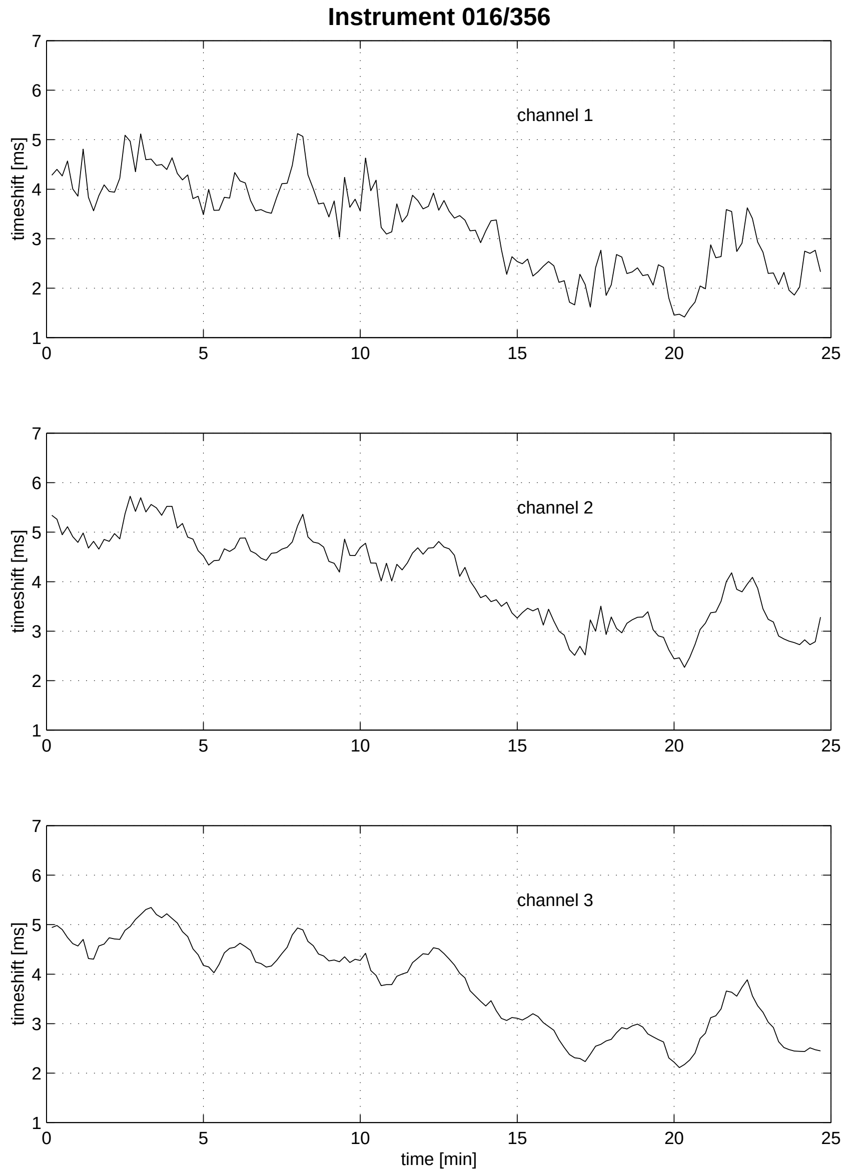

Figure 15: Instrument016-356

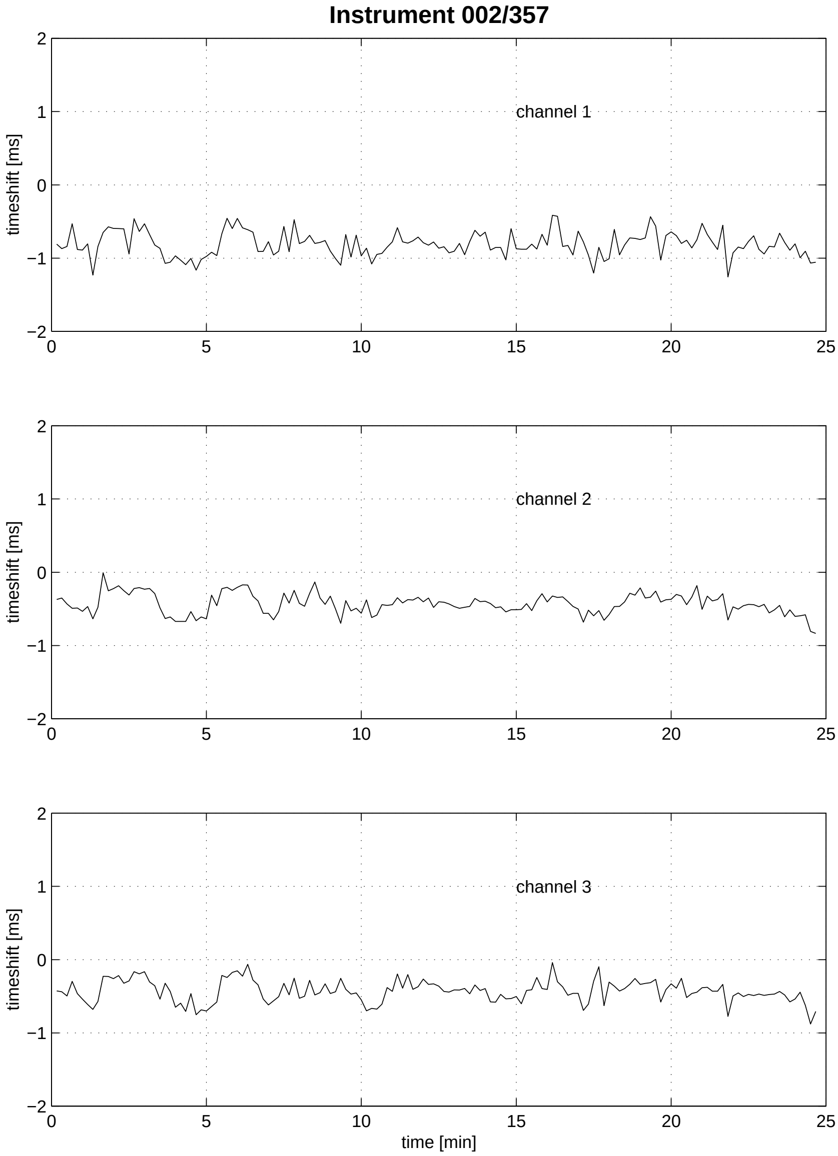

Figure 16: Instrument002-357

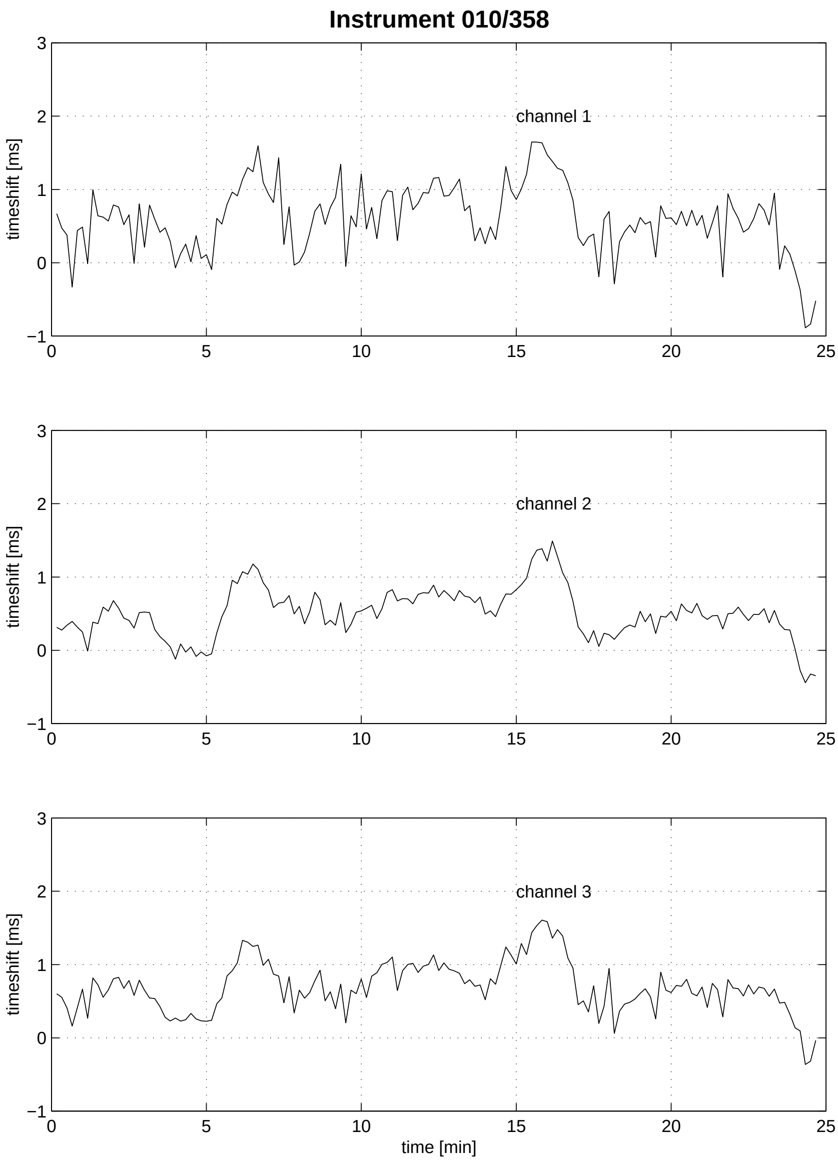

Figure 17: Instrument010-358

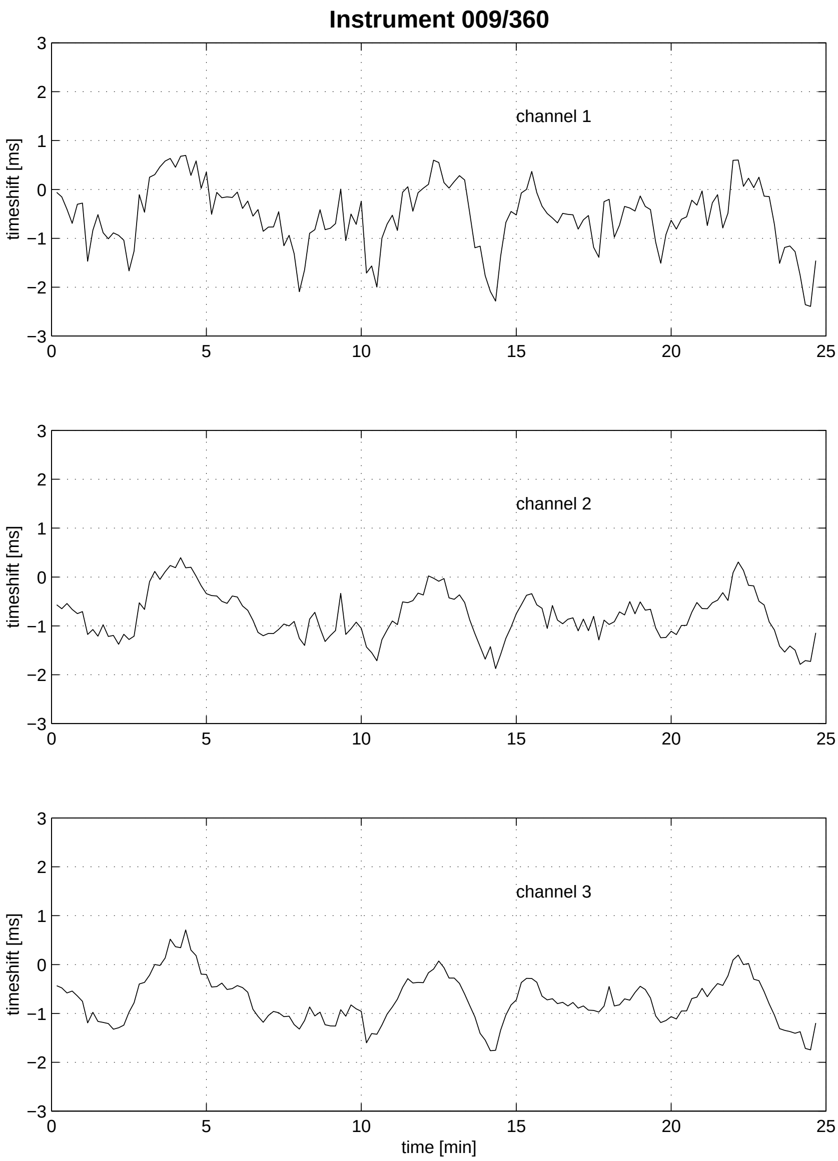

Figure 18: Instrument009-360

B GPS/DCF time shifts

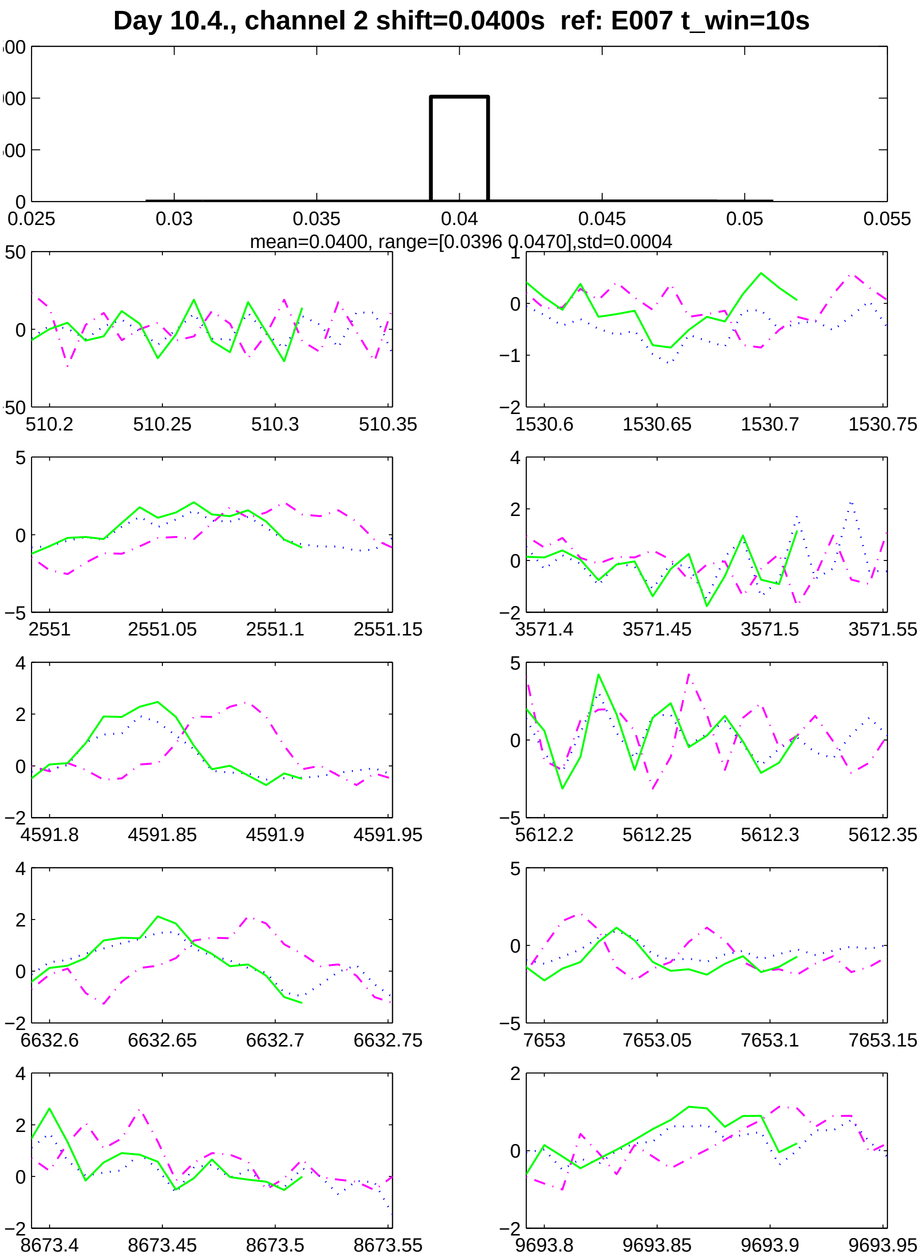

Figure 19: Time shift between Mars light PS 12G from Potsdam and Mars88 DCF E07 from ETH during the measurement of April 10 2002. Channel 1 (North-South) is compared in the frequency domain on 10s windows.

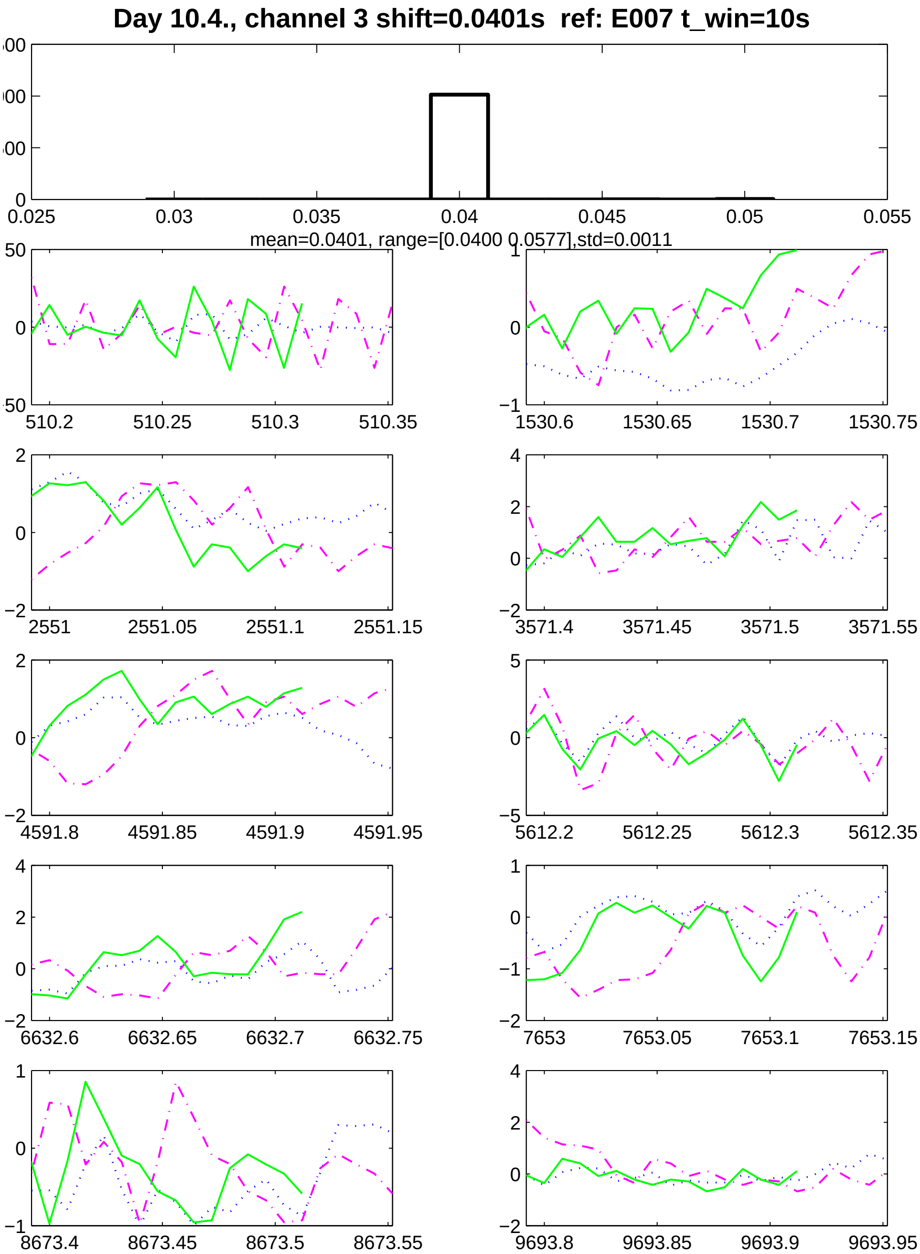

Figure 20: Time shift between Mars light PS 12G from Potsdam and Mars88 DCF E07 from ETH during the measurement of April 10 2002. Channel 2 (East-West) is compared in the frequency domain on 10s windows.